Section 5

Advanced Land Imager

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Topics of Discussion

- ***ALI Overview***
- ***Design and performance***
- ***Pre-launch Calibration and Characterization***
- ***Application to future Landsat instruments --- technology transfer***
- ***On-orbit performance assessment***
- ***Summary***

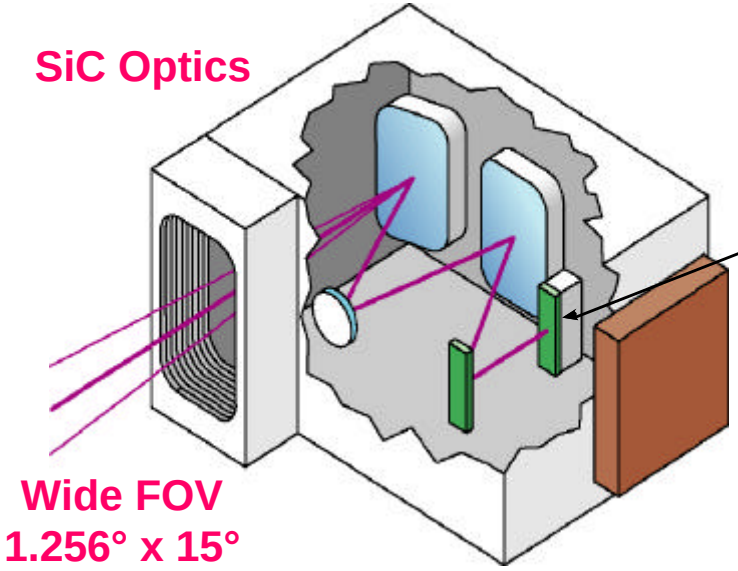
EO-1 Advanced Land Imager Overview

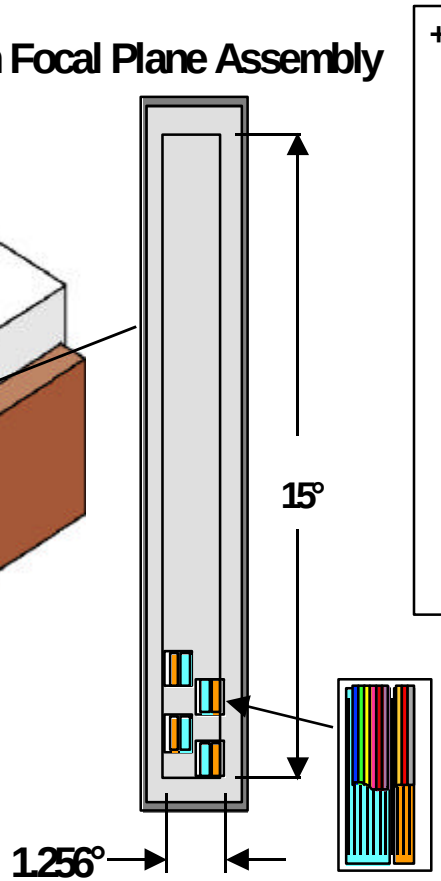
- *Primary instrument on the first Earth Observing Mission (EO-1) of NASA's New Millennium Program (NMP)*
- *Objectives are to flight validate key technologies*
  - *Data continuity, advanced capability and cost reduction for future Landsat instruments*
  - *Innovative approaches to future land imaging*
- *The ALI instrument was designed and developed by MIT Lincoln Laboratory with NMP instrument team members*
  - *Raytheon SBRS for the focal plane system*
  - *SSG Inc. for the optical system*

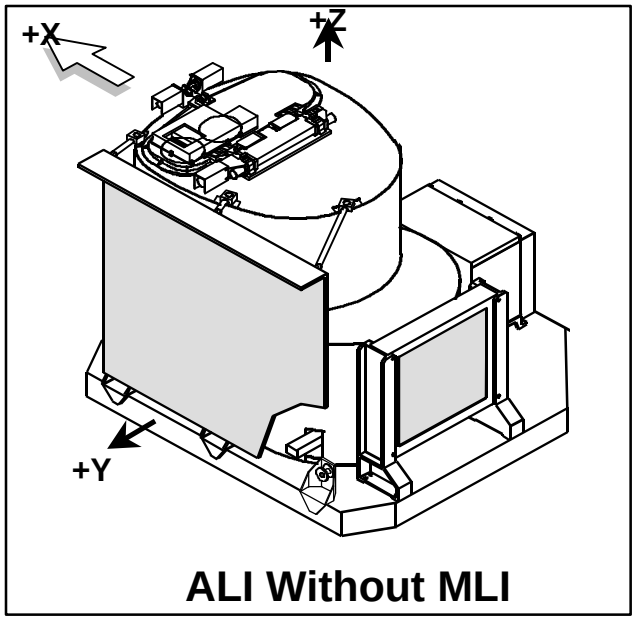
Driving Requirements

- *Instrument architecture developed from technologies represented on the NMP IPDT*
- *Flight validation of technologies required to significantly reduce the risk for future missions*
- *Flight data must be amenable to science validation*
- *Measurement requirements were developed*
  - *From the bottom up by the IPDT*
  - *In collaboration with the earth science community*
- *Design must be scaleable to a full-up instrument*

Advanced Land Imager (ALI)





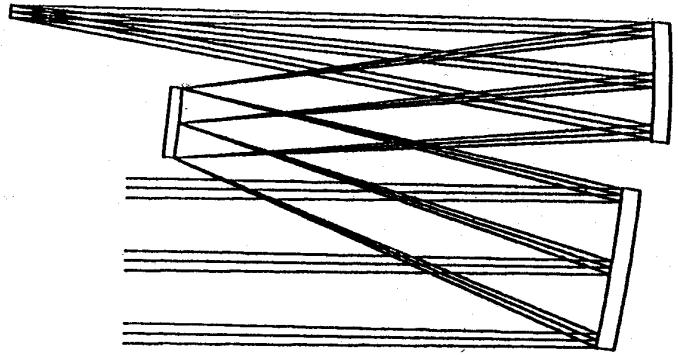


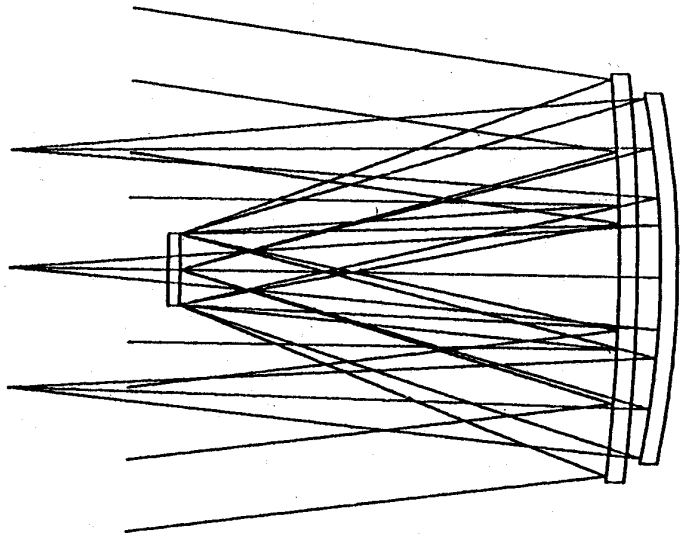
Band	Ground Sampling
Pan	10 m
MS	30 m

Multispectral
Panchromatic +
6 VNIR + 3 SWIR
220 K

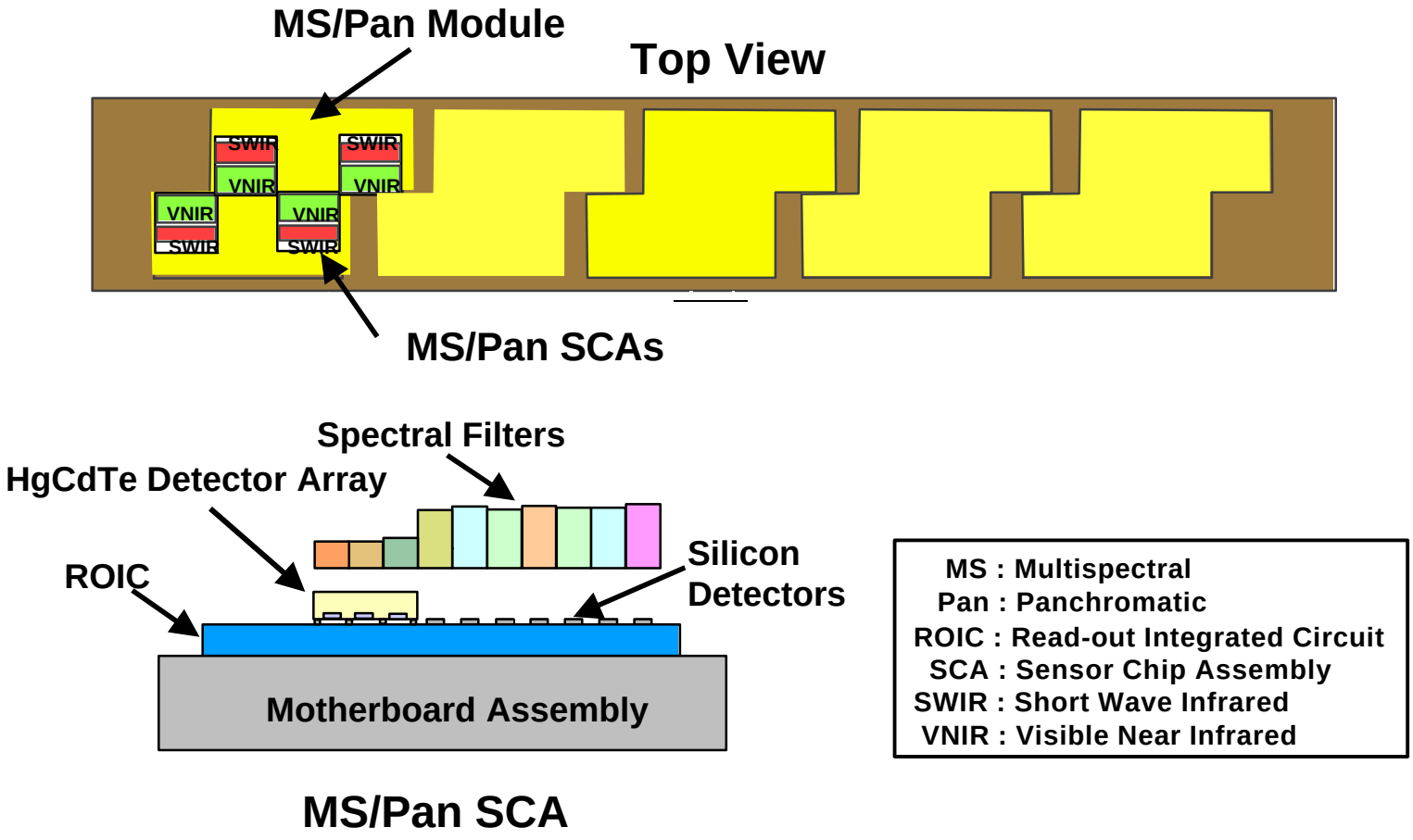
ALI Optical Design Form

- All reflective Cooke Triplet
  - Aspheric primary
  - Ellipsoidal secondary
  - Spherical tertiary
- Aperture stop on secondary mirror
- Non-relayed design
- Near telecentric
- FOV = 1.256 x 15 degrees



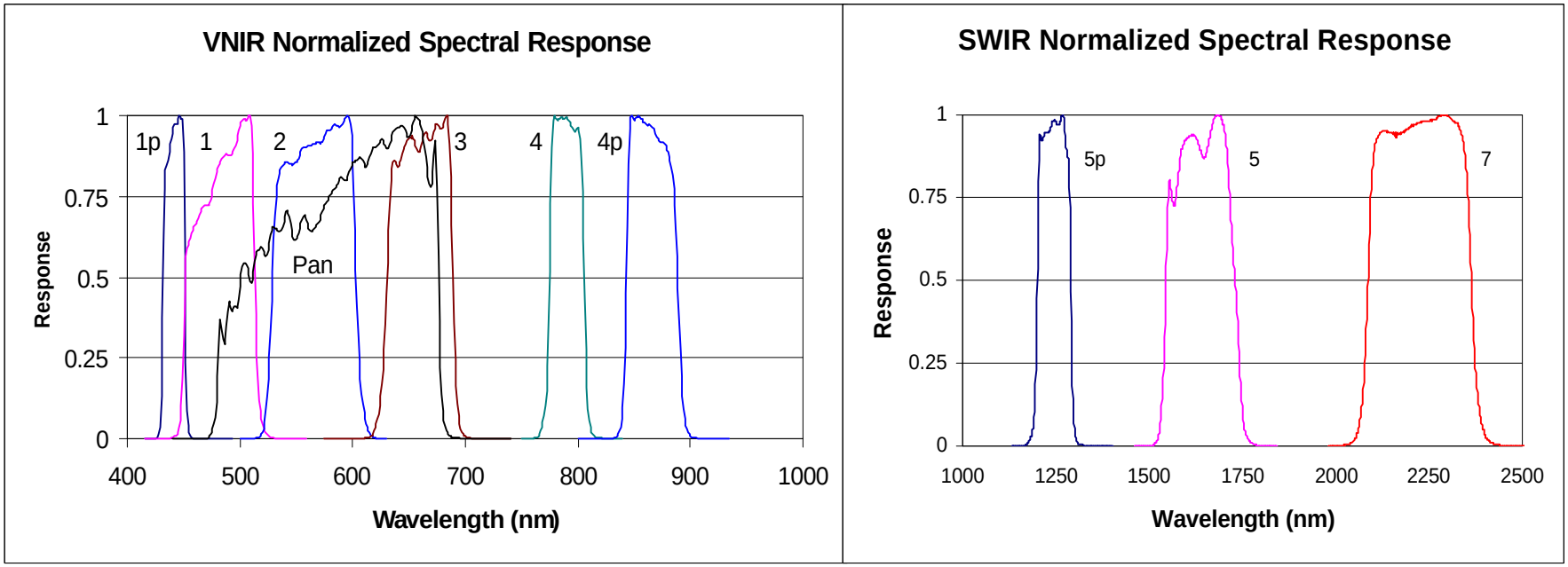


Main Focal Plane Assembly



MS : Multispectral
Pan : Panchromatic
ROIC : Read-out Integrated Circuit
SCA : Sensor Chip Assembly
SWIR : Short Wave Infrared
VNIR : Visible Near Infrared

ALI Spectral Response Functions

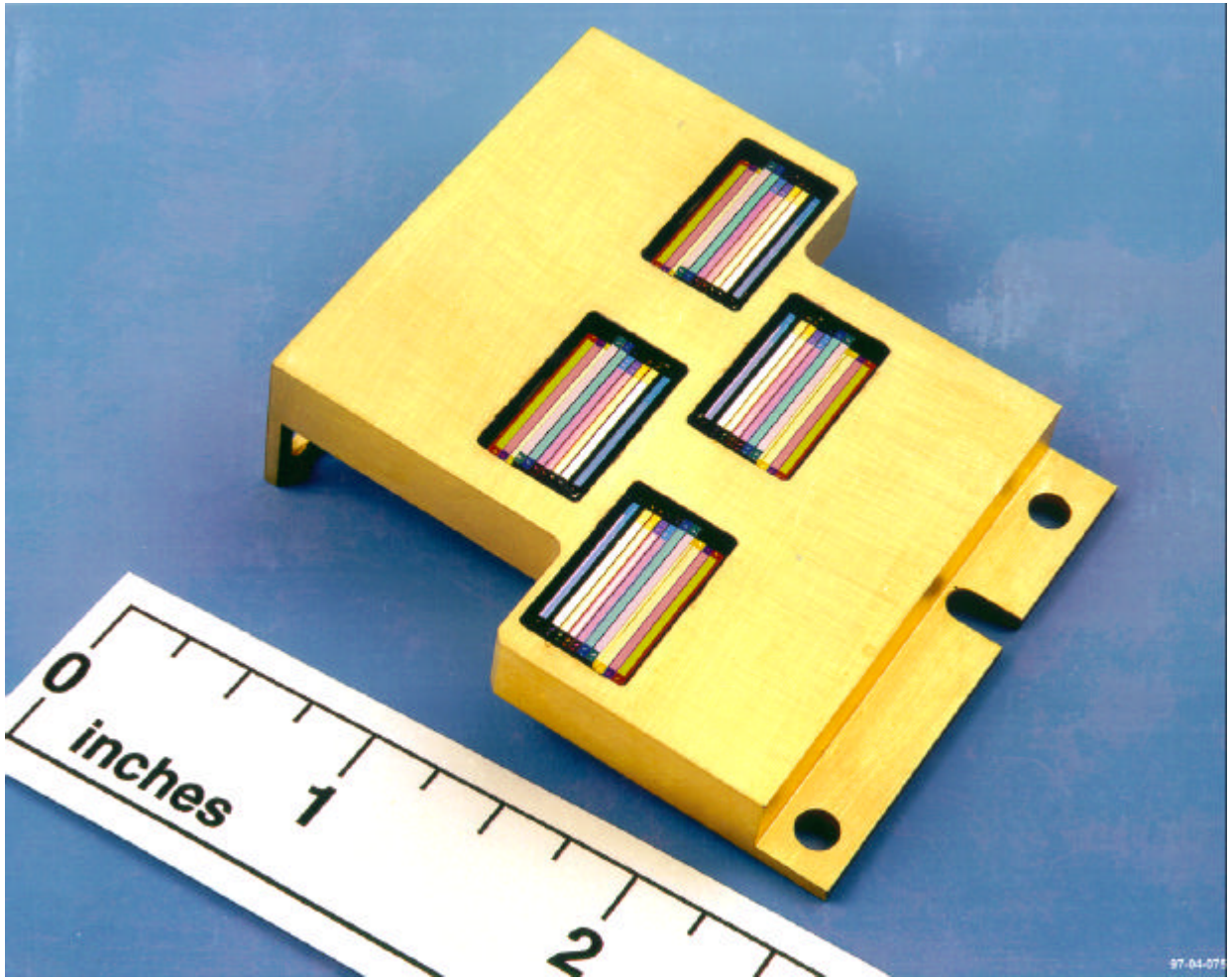


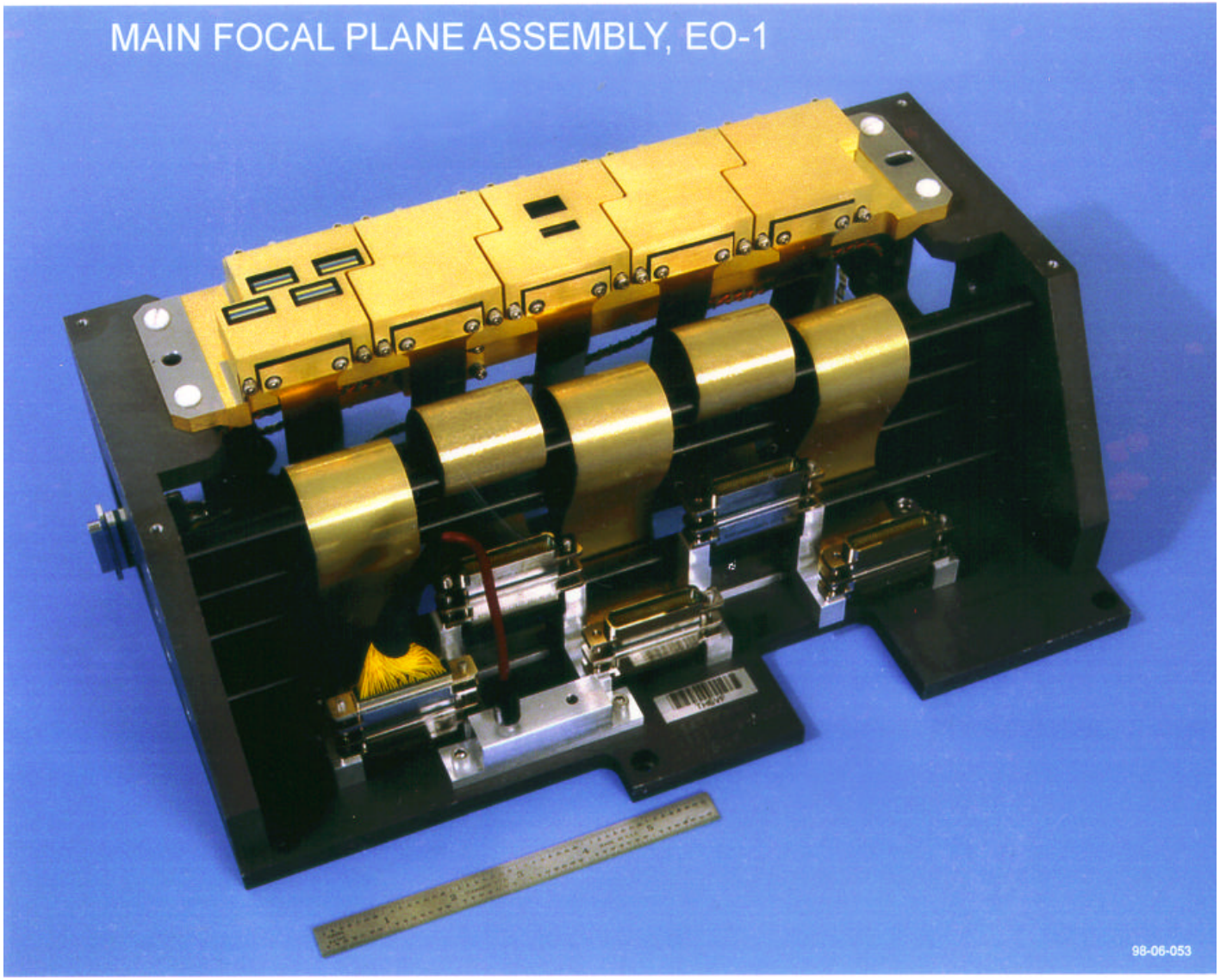
EO-1 ALI MS/PAN

Spectral and Spatial Coverage

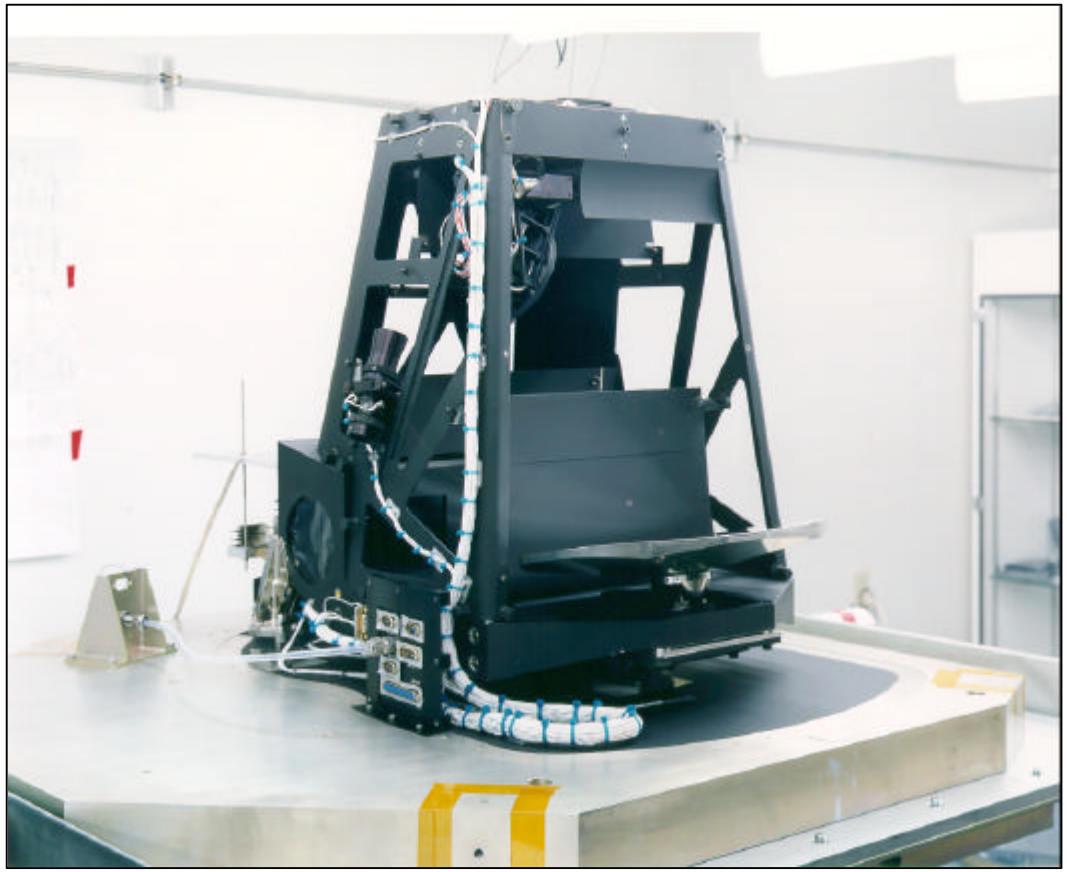
Band	Wavelength(mm)	Detector Type	GSD (m)	# of Detectors
Pan	0.480-0.690	Si Photodiode	10	3840
MS-1’	0.433-0.453	Si Photodiode	30	1280 Per Band
MS-1	0.450-0.515			
MS-2	0.525-0.605			
MS-3	0.630-0.690			
MS-4	0.775-0.805			
MS-4’	0.845-0.890			
MS-5’	1.200-1.300	PV HgCdTe	30	1280 Per Band
MS-5	1.550-1.750			
MS-7	2.080-2.350			

MS/PAN Flight Module




MAIN FOCAL PLANE ASSEMBLY, EO-1
98-06-053

Partially Assembled Flight ALI

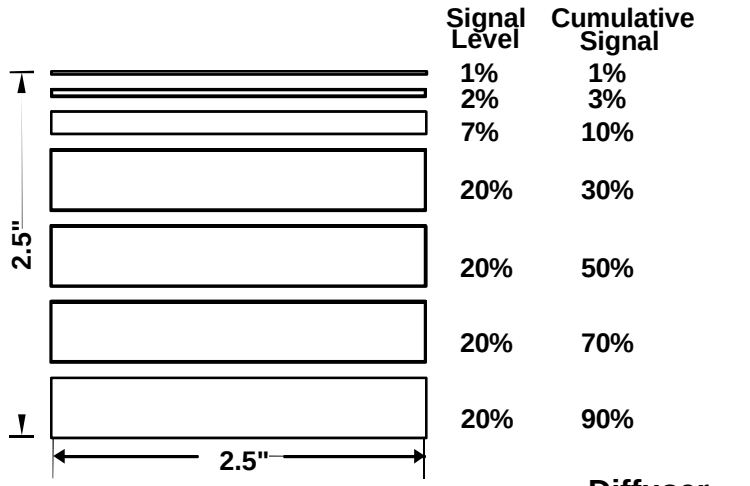


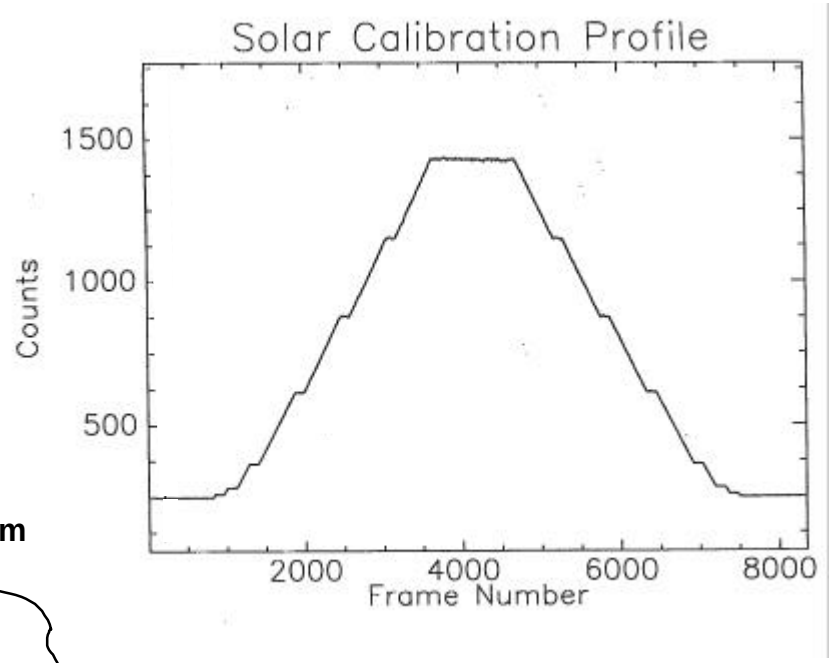
Telescope features

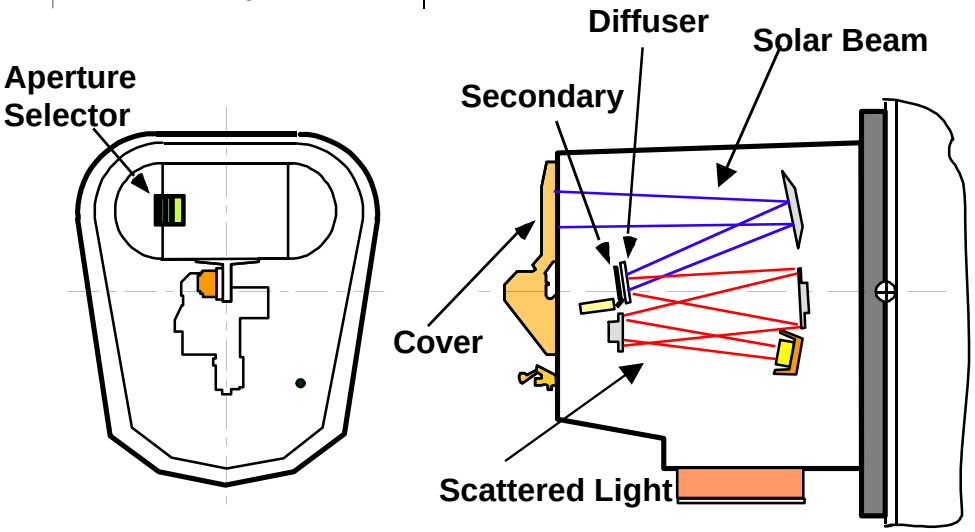
- 12.5 cm entrance pupil
- 15° x 1.26° field-of-view
- Telecentric, f/7.5 design
- Unobscured, reflective optics
- Silicon carbide mirrors
- Wavefront error = 0.11 l RMS @ 633 nm

Installation of ALI into Thermal Vacuum Chamber

Solar Calibration





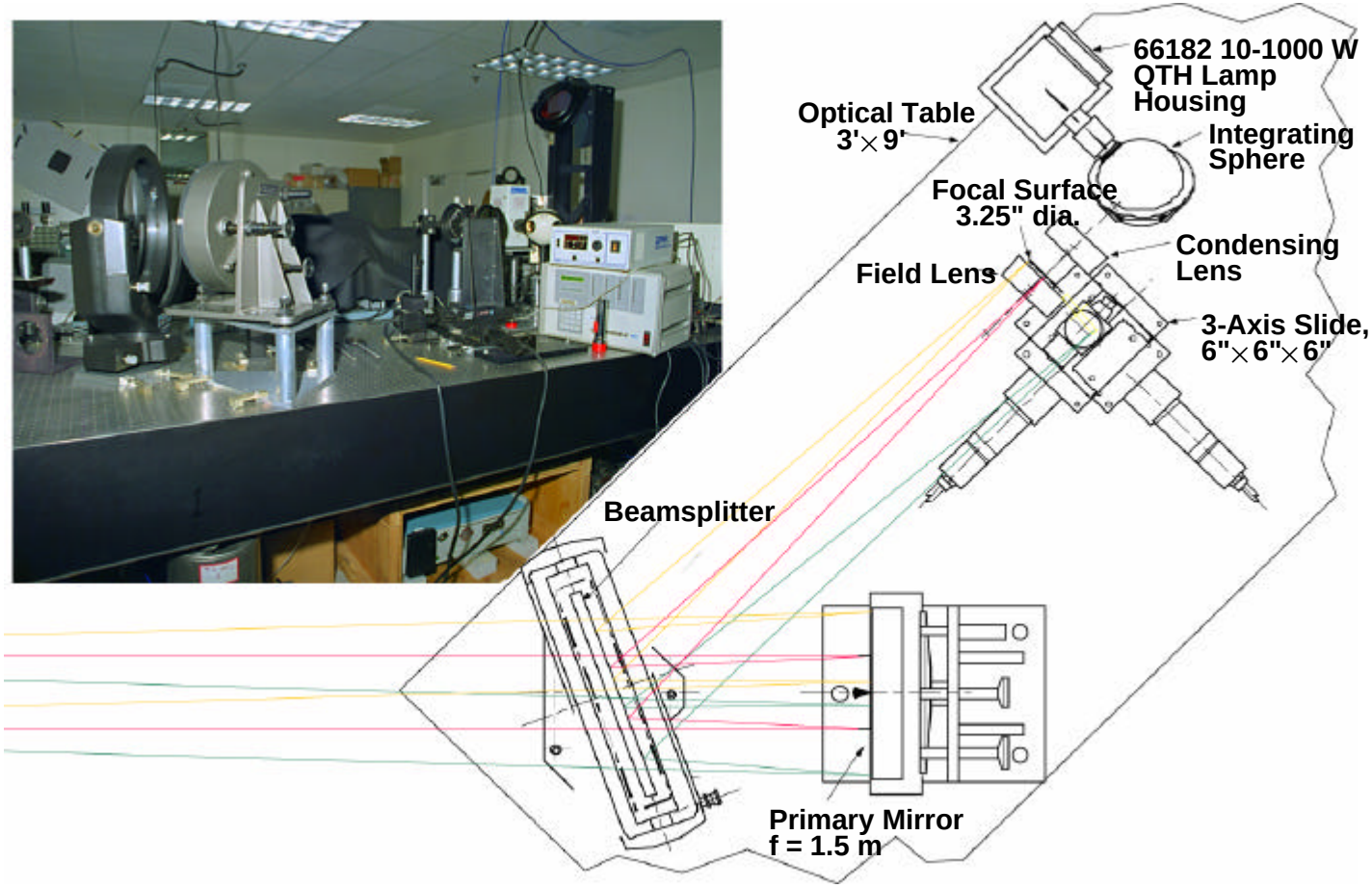


ALI Calibration Matrix

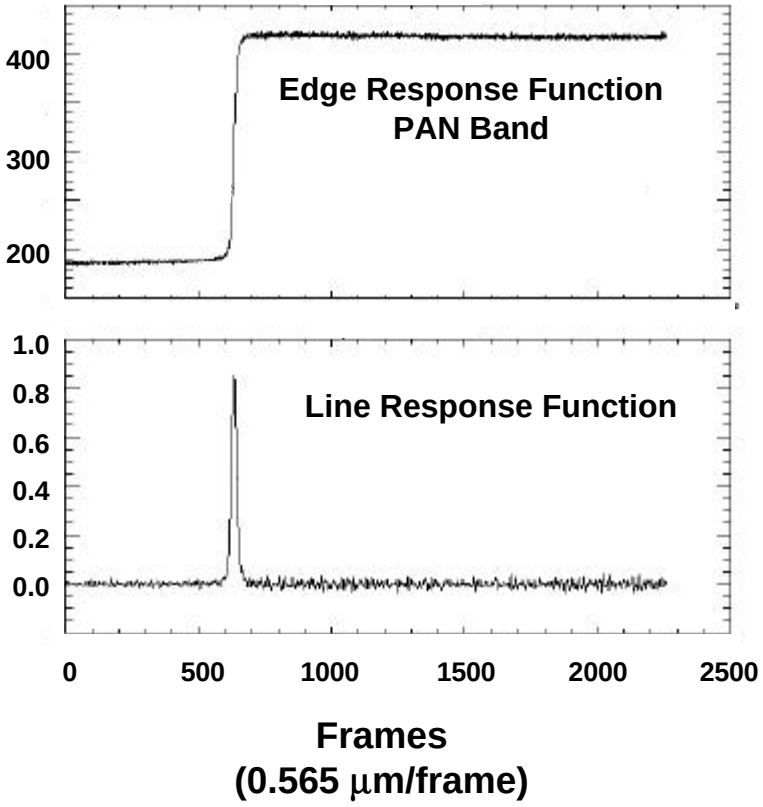
	Spectral Response Function	Response Coefficient	Zero Signal Offset	Pixel Angular Position	Modulation Transfer Function
Component Tests and Analysis	●	○	○	—	○
Subsystem Tests: Telescope and MS/Pan	○	○	○	○	○
Instrument-Level Laboratory Tests	●	●	○	●	●
On-Orbit Measurements:					
Solar Calibration	—	●	—	—	—
Dark Current	—	—	●	—	—
Int. Reference Lamps	—	○	—	—	—
Lunar Scans	—	○	○	—	○
Earth Scenes	—	○	—	○	○

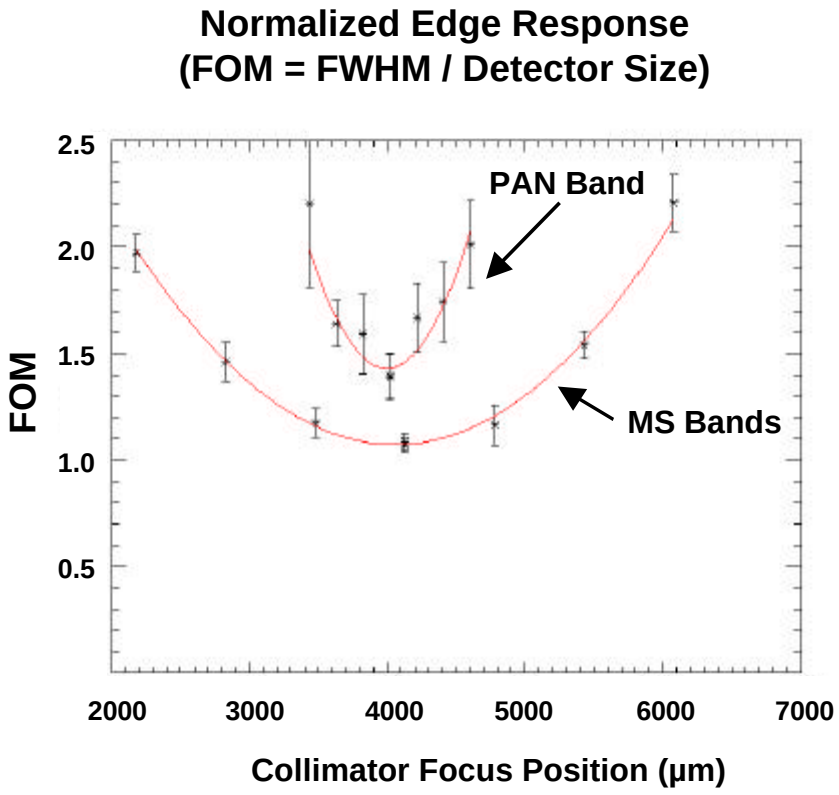
● Primary Measurement ○ Secondary Measurement

Imaging Test Optics

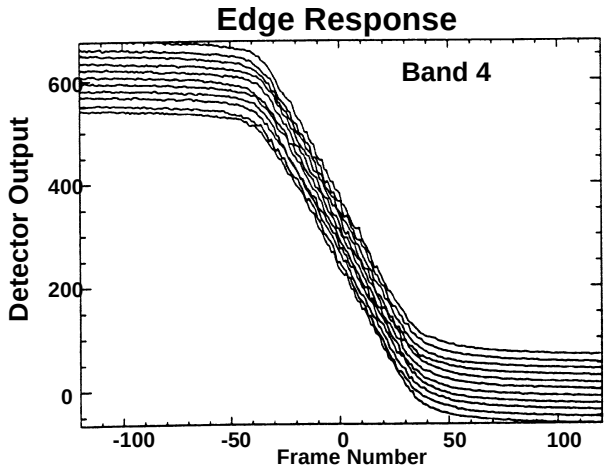


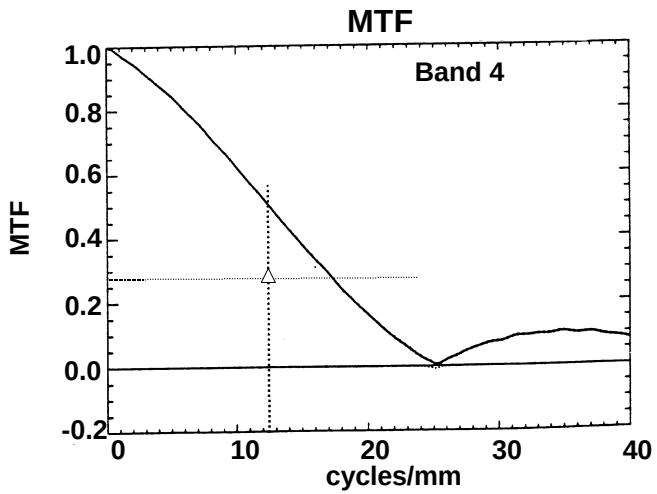
Focus Test

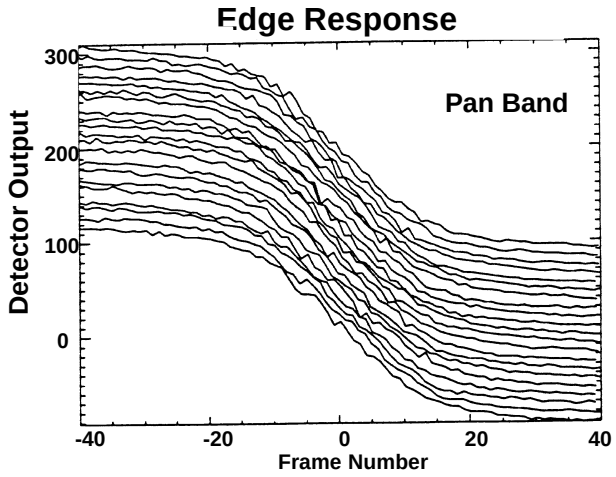

Edge Response Function
PAN Band
Line Response Function
400
300
200
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
Frames
(0.565 μm/frame)


Normalized Edge Response
(FOM = FWHM / Detector Size)
PAN Band
MS Bands
FOM
2.5
2.0
1.5
1.0
0.5
2000
3000
4000
5000
6000
7000
Collimator Focus Position (μm)

MTF Performance







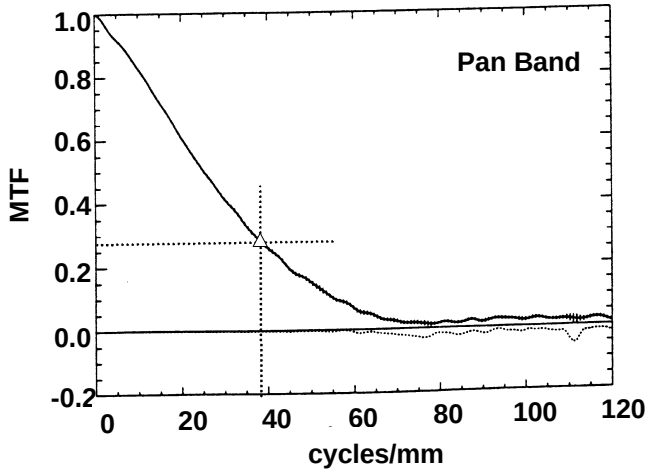
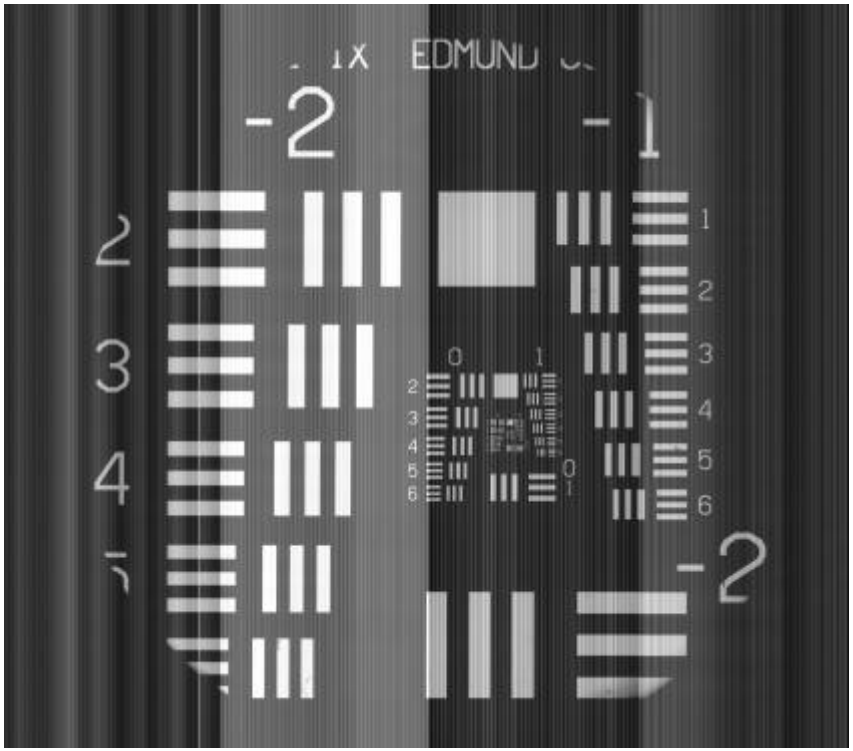
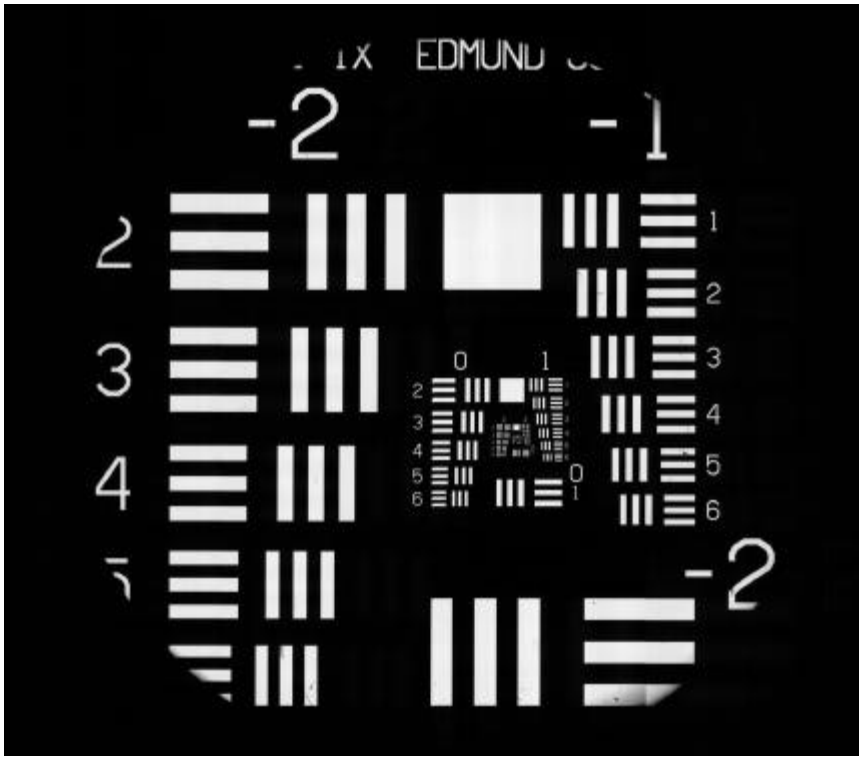


Image Reconstruction and Calibration

MS Band 1

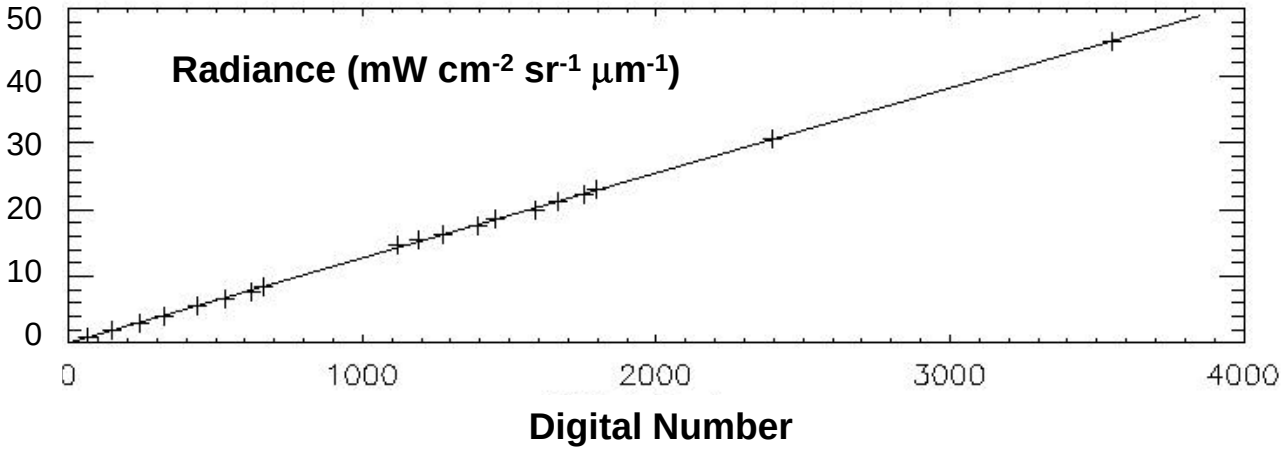


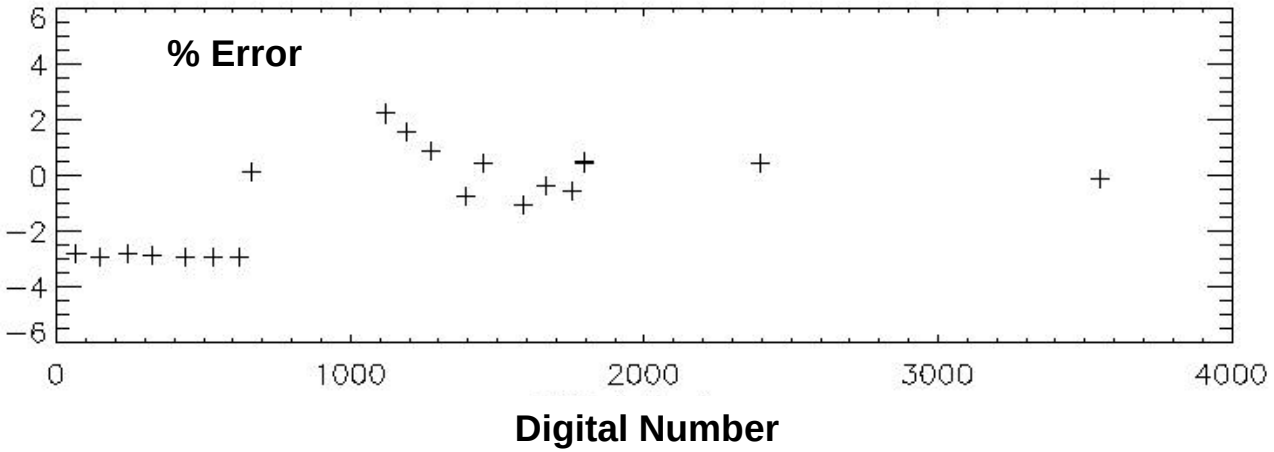
Reconstructed Raw Image



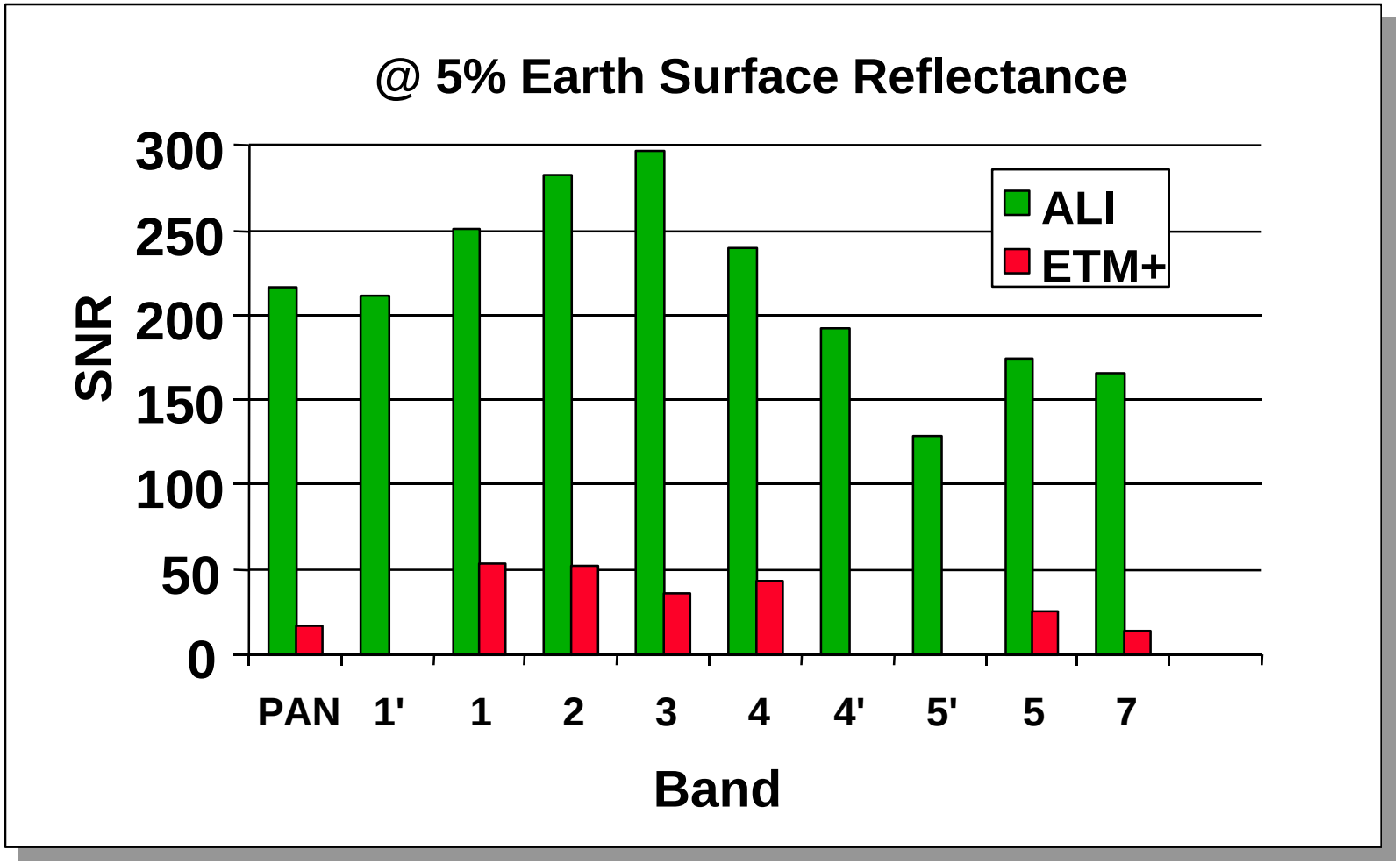
“Calibrated” Image

ALI Dynamic Range and Linearity





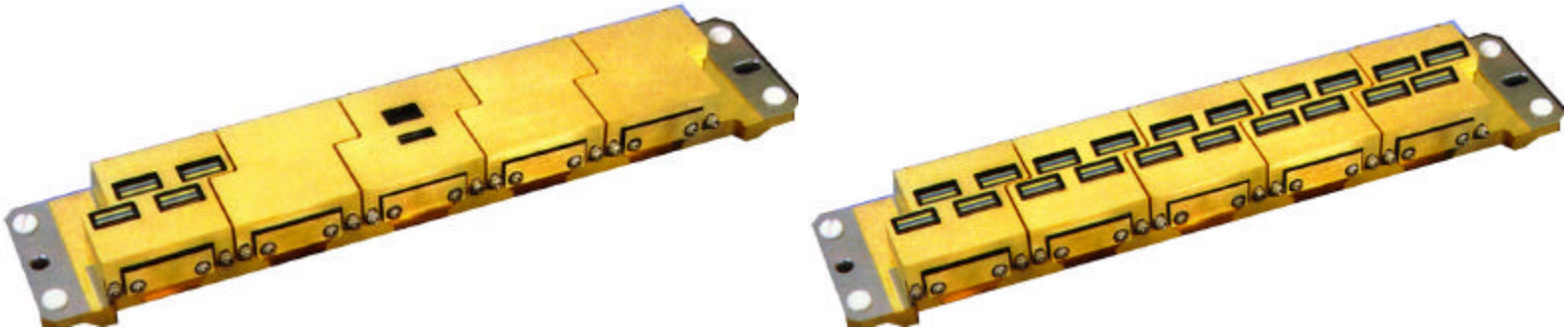
ALI SNR Performance



Growth Path to Advanced Instrument

Populate focal plane with 5 MS/PAN modules

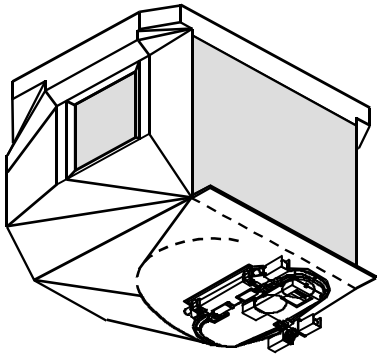
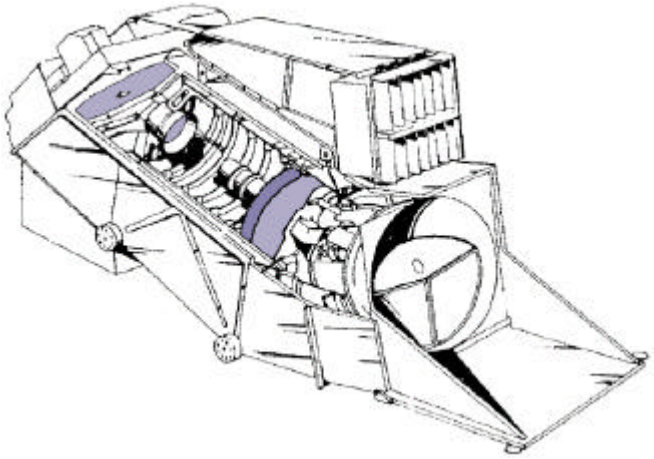
- Full 185 km wide field-of-view
- Main Focal Plane bench designed for 5 modules



Changes required to accommodate full MS/PAN coverage

Resource	*ALI*	*Advanced Landsat*
Data Ports	1	5
Data Rate	102.4 Mb/s	512 Mb/s
FPE Power	~ 15 Watts	~ 50 Watts
FPA Size	30.7 x 6.6 x 5.2 cm	30.7 x 6.6 x 5.2 cm

Land Imaging Instrument Comparison

ALI - Concept for Future Landsat Instrument		Enhanced Thematic Mapper (ETM+)
		
100	Mass (kg)	425
100	Power (W)	545
70×75×75	Size (cm)	196×114×66
7, 3, 0	VNIR, SWIR, LWIR Bands	5, 2, 1
10, 30	Pan, MS Resolution (m)	15, 30
4-10	Relative SNR	1

ALI Technology Transfer

- **Objectives**
  - Reduce cost and improve data quality for the LDCM
  - Exploit NASA's investment in the ALI technologies
  - Utilize Lincoln Laboratory's unique ALI expertise
- **Methods**
  - Publications, reports, and documentation
  - NASA-sponsored workshops at Lincoln Laboratory
  - Technical support of an industry/government sensor development
  - Characterization and calibration of sensors at Lincoln Laboratory
  - Sensor integration and test by Lincoln Laboratory
- **Funding for MIT/Lincoln Laboratory (an FFRDC)**
  - Directly from NASA or other government agency
  - Cooperative Research and Development Agreement with industry developer

Summary

- *The Advanced Land Imager is the primary instrument on the first Earth Observing Mission (EO-1) of NASA's New Millennium Program (NMP)*
- *The ALI has undergone extensive pre-launch calibration and characterization and has demonstrated excellent performance*
- *The EO-1 mission is now in progress and should successfully flight-validate the NMP technologies*
- *These technologies provide a path for lower cost, higher performance, future Landsat instruments*
- *MIT Lincoln Laboratory is interested in helping NASA transfer the ALI technology for application to future Landsat missions*

On-Orbit Performance Assessment

- *Preliminary flight data and status*
- *On-orbit performance assessment plan*
- *Summary*

ALI Performance in Space

- *ALI was turned on on November 25, 2000 (Day 5)*
- *Launch latches were released and a series of comprehensive tests were conducted showing nominal instrument performance*
  - *The temperature control has been excellent*
- *Obtained four earth scenes with the spacecraft pointing to nadir, i.e., the active part of ALI covering a swath 55 to 92 km east of the S/C ground track*
  - *Alaska, north-east of Anchorage*
  - *East Antarctica*
  - *Marshall Islands*
  - *North-central Australia*

Mission Operations

- *The first earth scene with all instruments operating simultaneously was obtained on December 1, 2000*
- *On December 15, 2000, EO-1 achieved its intended position, 1 minute behind Landsat 7*
- *On December 21, 2000, EO-1 began to point towards the desired target within the Landsat swath. Until then, most of the recorded scenes represented targets of opportunity with the S/C in a nadir pointing mode*
- *Comparison of ALI and Landsat scenes has not yet begun*
- *The number of scenes per day has gradually increased from two to six. Eight is the planned maximum in the first four months.*
  - *Four scenes per day will be acquired in the remainder of the first year*
  - *No firm plans yet for the remainder of life (EO-1 has 5 years worth of consumables)*

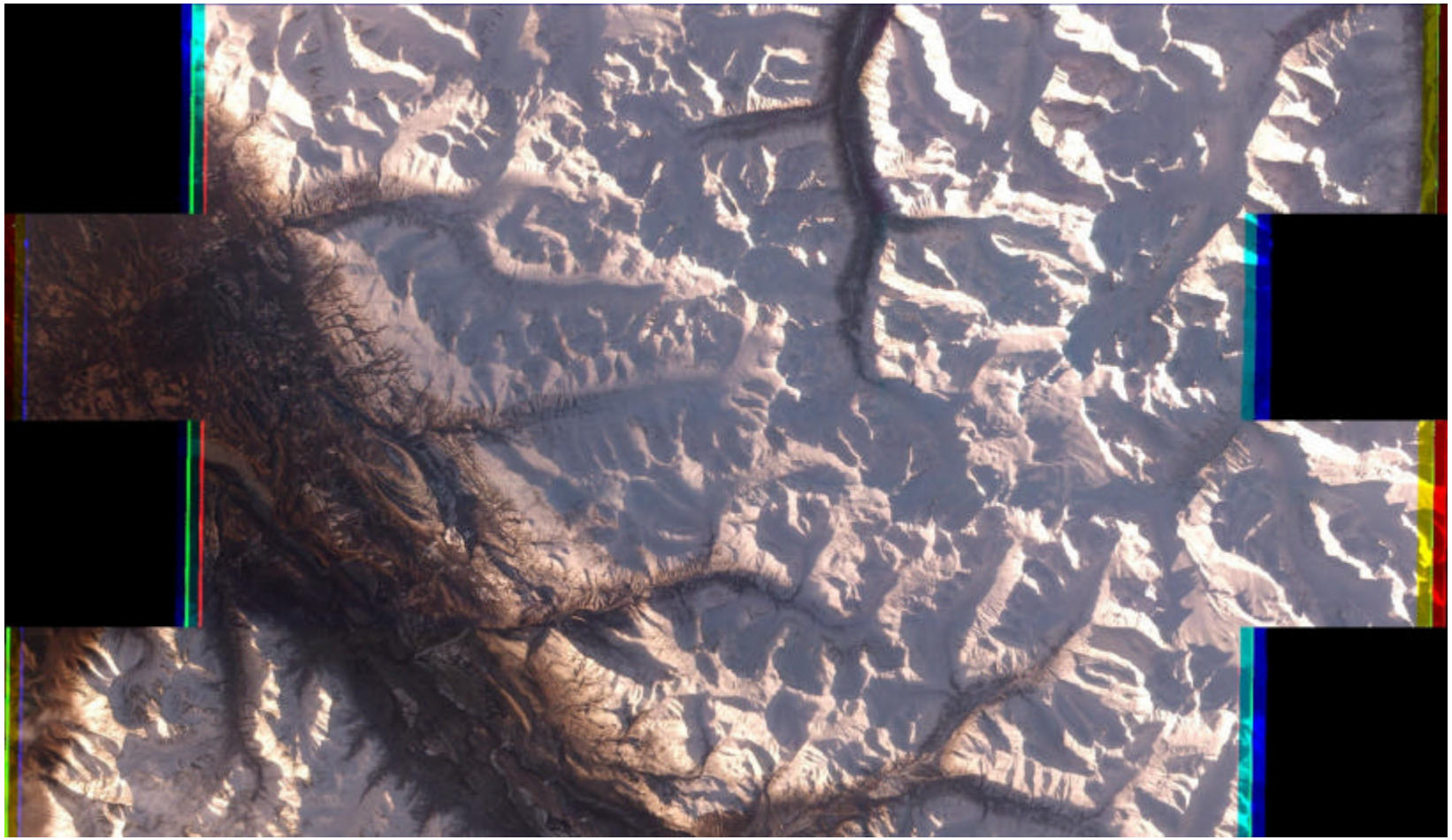
Focal Plane Contamination

- *Ground testing had revealed fine droplets forming on the cold focal plane after several days at –53 C. They boil off between –20 C and –10 C*
- *ALI is equipped with enough heaters to raise the focal plane temperature to –3 C which has been effective in evaporating the unknown contaminant*
  - *Bake-outs on-orbit were planned every two weeks*
- *In space, it was noted that the contaminant accumulation is more severe and occurs faster than on the ground. The bake-out is still effective in boiling off the contaminant(s).*
  - *Bake-outs will be conducted weekly and the performance will continue to be monitored closely*

First ALI Image: Sutton, AK

(2000:330, MS 3-2-1)

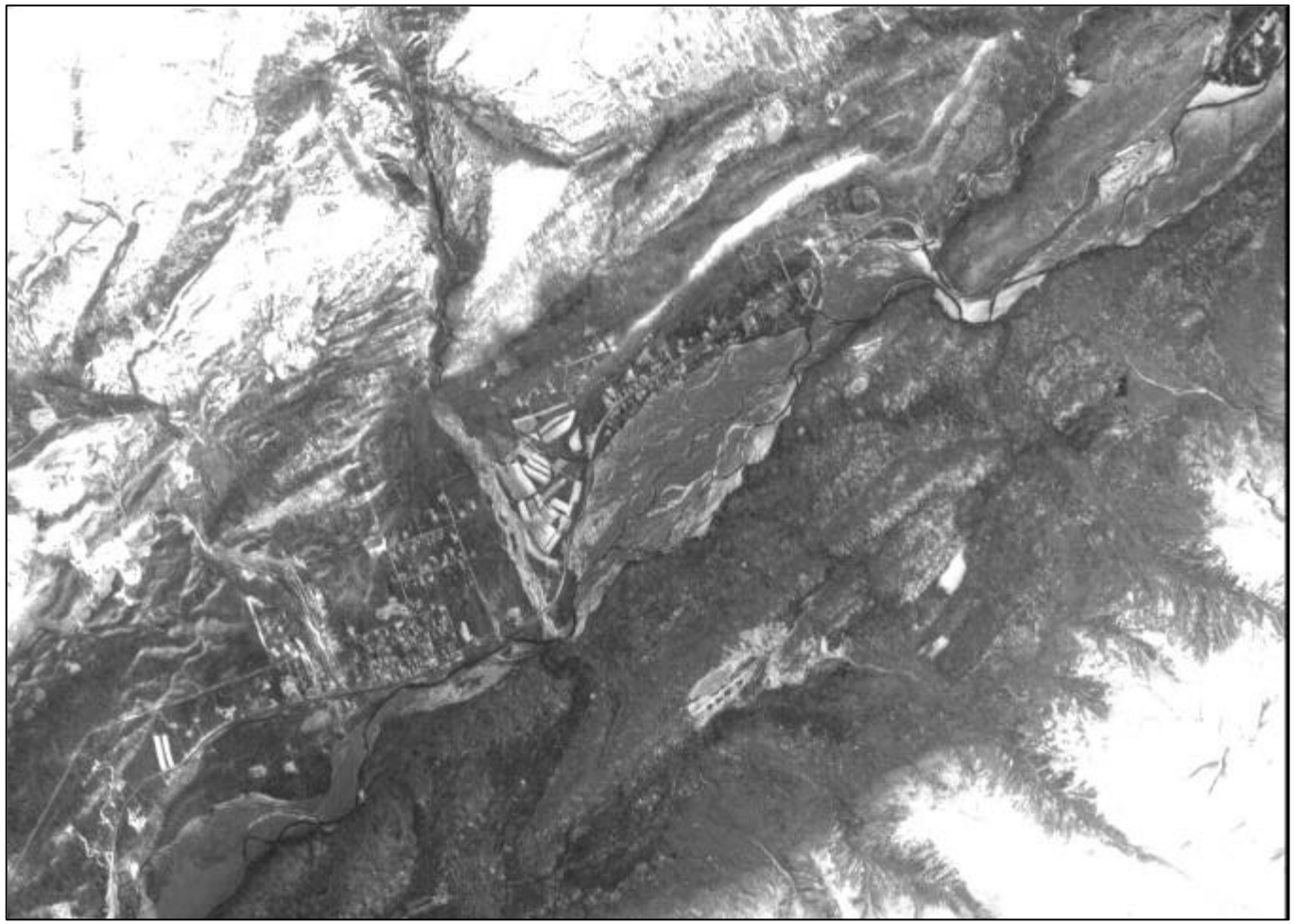
N



First ALI Image: Sutton, AK

(2000:330, Pan zoom)

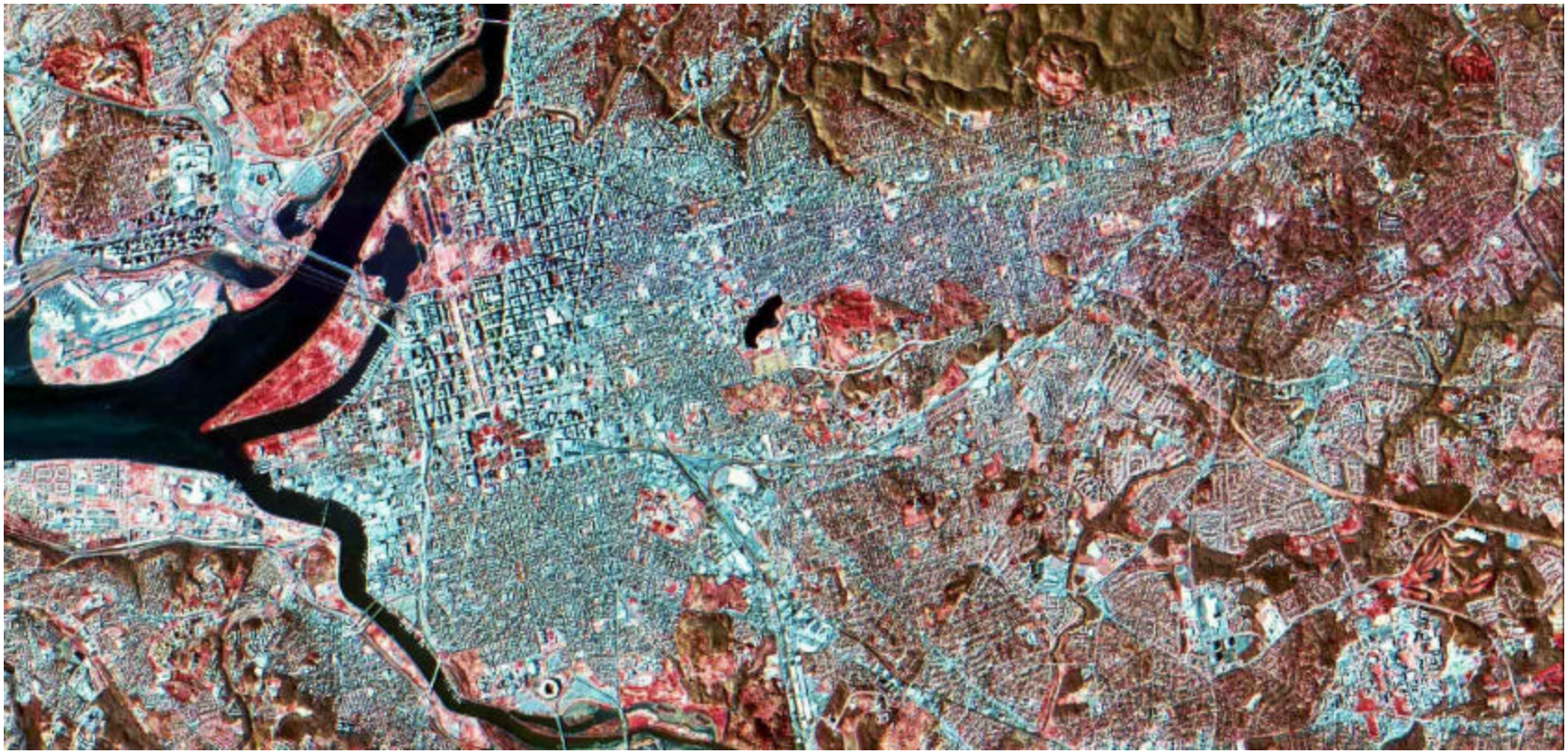
N



Washington, DC

(2000:356, MS 4-3-2)

N



Washington, DC

(2000:336, Pan zoom)

N

Delaware Coast

(2000:338, MS 4-3-2)

N

Oahu,HI

(2000:354, MS 3-2-1)

N

Focal Plane Functional Tests

- Zero signal noise characteristics
- Internal lamp illumination
  - Responsivity
  - Linearity
  - Stability
  - Contamination assessment
  - On-orbit sensitivity to FPA and optics temperature
  - Evaluation of dead and under performing pixels
- Focal plane decontamination

ALI Technology Validation: Spatial Tests

- *Functional test of end to end imaging*
- *Focus*
  - *Point spread*
  - *Edge spread*
  - *Line spread*
  - *MTF*
- *Relative pixel line of sight*
- *Band to band image displacement accuracy*
- *Image artifacts*

ALI Technology Validation: Radiometric Tests

- *Pixel to pixel calibration (flat field)*
- *Calibration stability*
- *Absolute calibration*
  - *In-band*
  - *Band to band*
- *Dynamic range*
  - *Saturation*
  - *Noise*
- *Sensitivity (SNR)*
- *Solar calibration*
- *Lunar calibration scan*
- *Calibration corrections for leaky pixels*
  - *Linearity*
  - *Dynamic range*
- *Stray light effects*
  - *Spatial*
  - *Radiometric*

Generic Data Collection Events (DCE)

- **A.** Large flat metropolitan area with shore line
  - High contrast edge lines and points
  - Well known locations of key features
- **B.** Extended high albedo source with small dark regions
  - Clouds over ocean
- **C.** Steep topography
- **D.** Long bridges
- **F.** Large area with uniform known radiance (5-50% albedo)
- **G.** Adjacent regions with sharp boundaries and having different, uniform, but not necessarily known radiance levels
- **H.** Large area with uniform but unknown radiance
- **J.** MODIS calibration sites
- **K.** Landsat 7 geometric calibration sites
- **L.** Sun
- **M.** Moon
- **N.** Closed Cover (dark current)
- **O.** Night view of brightly lit metropolitan area
- **S.** Ground truth and under-flight targets
- **T.** Long duration target
- **U.** Angular dependence demonstration

Summary

- *The performance of the Advanced Land Imager in space has been nominal.*
- *The radiometric calibration coefficients will be revised based the imaging of known ground scenes and the solar calibration.*
  - *An improved algorithm has been developed to deal with the two leaky pixels.*
  - *Weekly bake-outs of the focal plane will be conducted to boil off the accumulating contaminants.*
- *The required data base is been collected and will be followed by in-depth analysis of all aspects of instrument performance.*